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# NATIONAL BUREAU OF STANDARDS REPORT

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## PERFORMANCE CHARACTERISTICS OF EXTERIOR WALLS

Progress Report for Period Ending December 31, 1965

by

J. V. Ryan

to

Federal Housing Administration  
U.S. Department of Housing and Urban Development  
Washington, D. C.



U.S. DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS

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NBS PROJECT

NBS REPORT

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U. S. DEPARTMENT OF COMMERCE  
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## 1. INTRODUCTION

The objectives of this project are to adapt or develop test methods and techniques for the measurement of the performance characteristics of exterior walls, and to provide values obtained by such tests when applied to representative walls. This project was designed to bring under consideration all the characteristics of exterior walls and to determine which are of importance. For the latter, means of measurement are sought and values obtained. These are expected to form the basis for decisions as to the levels of performance against which to judge walls of various types.

## 2. PROJECT PLAN

The plan of the project called for (1) an analysis of the functions of exterior walls in order to develop a list of all characteristics and the selection of those subject to physical measurement, (2) review of existing test methods having potential applicability, (3) testing of representative samples by these methods, (4) development of additional test methods and apparatus as needed, (5) measurement of the performance characteristics of samples of representative wall systems by all the various methods, and (6) where possible, suggest limiting values for each of the significant wall performance characteristics subject to physical measurement.

## 3. ACTIVITIES

The item number (1) under Project Plan was completed in an earlier period, except as review may be required in the light of progress under the other items. Work has continued under items (2), (3), and (4) and began under item (5). This work is being carried out in all but one of the Sections of the Building Research Division.

As a result of conferences among the Division staff engaged in the project, and with staff of the Federal Housing Agency, a

set of six wall constructions were agreed upon for submission to tests, per item (5) of the Project Plan: These are:

1. Framing: 2x4's, common pine or fir, 16 in. o.c. with firestops near midheight.

Exterior: 1/2 in. insulating fiber sheathing nailed to studs; 1 in. air space; single wythe 4 in. common face brick, with ties nailed to framing (through sheathing).

Interior: single layer of 1/2 in. aluminum foil backed gypsum wallboard, nailed to studs with joints vertical, joints taped and cemented, nailheads cemented; two coats of self-sealing latex base paint.

2. Framing: same as 1 above.

Exterior: 1/2 in. insulating fiber sheathing nailed to studs; 1x6 air-dried select wood drop siding nailed through sheathing to studs; painted per MPS.

Interior: same as 1 above.

3. Exterior: 4 in. common face brick backed with 4 in. cinder aggregate concrete block (3 oval hollow cores); each set in mortar.

Interior: 1x2 wood furring, nailed vertically, at 16 in. o.c., with horizontal strips at top, bottom, and midheight; drywall and paint as 1 above.

4. Sandwich wall (prefabricated) consisting of metal exterior skin, hardboard interior skin, and foamed in place plastic insulation to fill space between. Surface coatings (paint) as per normal production of the manufacturer.

5. Sandwich wall: same as 4 except hardboard skin on both faces.

6. Stressed skin, insulated, prefabricated.

For each of the above, enough material, or samples of prefabricated walls will be obtained in a single order to provide specimens for all tests to be carried out.

### 3.1 Structural and Water Permeability

#### 3.1.1 Racking Test

A racking-test frame has been assembled for applying diagonal loads to 8 x 8 ft wall specimens in a horizontal position. Spring-loaded yokes for applying simulated floor and roof loads to the wall are included in the equipment.

The decision to test the walls in a horizontal position instead of vertically was based on the results of trial tests on a Type No. 2 wall specimen. When racking asymmetrical walls, such as Type No. 2, there should be transverse restraint at the top and bottom edge to prevent the wall from warping. For practical reasons it is easier to provide this restraint with the test wall horizontal.

During our test development work the magnitude of the restraint will be measured.

Recent NBS studies have indicated that the racking resistance of load bearing walls is significantly affected by the vertical loads imposed by roof and floor loads. The intention is to rack test each wall type with three different vertical loading conditions. These superimposed vertical loads will be approximately 0, 0.5 and 1.0 of the calculated typical design load.

#### 3.1.2 Dimensional Stability Test

The distortion of the test walls subjected to temperature gradients will be measured in the air and water vapor transfer chamber.

#### 3.1.3 Wind Load and Water Permeability Test

In addition to the trial wall described in the July-December 1964 Progress Report a Type No. 2 test wall has been tested in the test chamber previously described. The reaction of both walls to the 50 psf wind load was quite similar, with a center deflection of about 0.5 in. No cracking or any other distress was noted. Both walls behaved elastically with only a small amount of permanent set. The Type No. 2 wall was retested after the rain test. The measured deflection of the damp wall was approximately 20% less than the dry wall. This increase in stiffness was probably due to the expansion of the wall frame and subsequent increase in restraint around the perimeter.

The water permeability test indicated that both walls were fairly water tight. The test on the trial wall indicated that about 15 hours of rain with a wind pressure of 10 psf would cause visible leakage on the interior. For the test on the Type No. 2 wall no visible water was noted on the interior until after 26 hours of continuous exposure. The through-wall leakage of the trial wall was about 1 lb/hr for a wind pressure of 10 psf and the rate increased rapidly with an increase in pressure.

The through-wall leakage of the Type No. 2 wall, although visible, was never great enough to measure, with the pressure at 10 psf. When the pressure was increased to 30 psf the leakage increased to about 30 drops a minute for about 30 minutes and then stopped. Subsequent increase in the pressure to 50 psf caused a temporary leakage of about 2 drops of water per minute. This leakage had practically ceased after about 10 minutes at 50 psf.

All indications were that the test wall of Type No. 2 was much more impermeable to wind driven rain than the trial wall. The main difference between the two walls affecting the permeability would seem to be the siding. The Type No. 2 wall was clad with wood drop siding which was finished, after application, with 2 coats of oil base paint (primer and finish). The trial wall was clad with a prefinished vinyl siding which could not be considered water tight.

Examination of the walls after test revealed two facts. These were:

1. That the use of interior grade plywood as sheathing would not be satisfactory if the siding is not water tight.
2. The workmanship of the man who painted the siding of the Type No. 2 wall was well above average because all exposed surfaces had been well coated. This above-average workmanship resulted in a well-sealed exterior surface. For this reason a second Type No. 2 wall may have to be tested for water permeability.

In order to arrive at some rational estimate of a reasonable period of exposure for the water permeability test a study was made of the Weather Bureau records for Washington and Miami, Florida. This was an hour-to-hour study of the records for 11 years. The data developed indicates that each year the Washington

area has a good chance of having a continuous rainy period of over 60 hours. The average rainfall during this period will be less than 0.1-in. per hour. Also, the probable maximum wind velocity (fastest mile) during this period would be only about 20-mph (less than 2.5-psf pressure). For the Miami area the probable longest rain period each year is over 70 hours, and the accompanying wind will reach a maximum of about 50-mph (10-psf pressure). The probable rainfall is about double that of the Washington area.

Originally it had been planned to use a rather short period of exposure as the exposure conditions were judged to be rather severe. The present thinking is that an exposure period of 72 hours is necessary, especially for constructions which have a built-in-reservoir for collecting leakage through the exterior surface.

#### 3.1.4 Compressive and Transverse Load Tests

The Type No. 2 wall has been tested using the compressive and transverse load test procedures of ASTM E-72. These procedures have been found to be satisfactory. The ultimate compressive load for the Type No. 2 wall was 10,500-lbs per lineal foot. Final failure was due to the flexural fracture of two studs at knots, although there was obvious differential movement between the gypsum wallboard and the top and bottom plates.

#### 3.2 Smoke Production

The apparatus for measurement of smoke production has been completed and checked out on a number of specimens. However, samples from the six walls described in paragraph 3. Activities, had not been made available in time for results to be included in this report. A detailed report on the apparatus is appended to this report and will be circulated to other laboratories in the fire research field. This is done to elicit the comments of other professional fire researchers, since the apparatus is of a new design.

#### 3.3 Air and Water Vapor Transfer

Construction of the environmental chambers to be used in gathering data on the performance of exterior walls has been completed. The chambers were constructed to provide enclosures that are to be both air- and vapor-tight and to be capable of maintaining air temperature and moisture content at a desired level. The interior and exterior surfaces were covered with

a vapor barrier material in addition to using a special plywood impregnated with a substance having a very low permeability. The wall cavity was filled with urethane plastic foam for insulating value and airtightness. The insulation was foamed in place after construction of the chambers and the vapor barrier material was applied after the foaming operation. The chamber to be used as a cold box is mounted in a fixed position and the other chamber (the warm box) is mounted on casters and can be moved away from the stationary chamber for insertion of a test specimen which will be mounted in a support frame. The frame is attached to an overhead trolley which can be moved to position the specimen against the opening in the chambers. Observation ports and doors are provided in each of the chambers.

Installation of the mechanical equipment (refrigeration system, dehumidification system and flowmeters for infiltration measurements) is almost completed. Until the mechanical equipment is ready other activities to ready the apparatus were carried on. Calibration of the chambers was made to determine if the chambers leak and the amount of air leakage when specified pressures are maintained within the apparatus. Instrument racks were built and instrumentation and controls for measuring the temperature, humidity, pressure and air leakage were installed.

After installation of the mechanical equipment and the required instrumentation, several dry runs will be made to check out the apparatus. It is proposed that: (1) The air leakage be determined at conditions (pressure differences across the wall specimen) representing winds from 5 to 30 miles per hours, with and without temperature variation of outdoor conditions; (2) measurement be made of physical deflection, if any, caused by thermal expansion or contraction; (3) determinations be made of when and where condensation forms, by measurements at selected points within the wall structure of relative humidity and temperature.

Preliminary test have been made to determine the amount and location of the leakage through the chambers after installation of instrumentation. Tests thus far have shown that the leakage for the equivalent of a 30 mph wind is less than 1/2 cubic foot per hour. Tests are also under way to determine the amount of leakage that occurs at the joints where the specimen mounting mask meets the steel support frame. A trial wall of 1/2-inch plywood was constructed in the frame to simulate a wall having no leaks, so that the leakage around the wall might be determined. This amount of leakage will be eliminated or subtracted from the leakage value of the specimen during the actual tests of infiltration. The chamber will be calibrated for leakage before each test.

The apparatus is instrumented to determine temperature, relative humidities, and leakage air flows. Fifty thermocouples are installed in the apparatus to give data on the temperature conditions of the air in the chambers, at points within the wall structure, and on the wall surfaces. Sixteen of the thermocouples can be connected to a continuous recorder and the remaining thermocouples can be read through an indicator at desired intervals. Twenty-four humidity sensing elements of the lithium chloride type can be used to sample conditions of the chamber air and the air within the wall structure. Control of the humidity is maintained by means of a humidity sensing device which causes humidification as necessary. Indications thus far have been that the system for humidity control is quite adequate, giving control to within one percent relative humidity. Eight of the elements can be recorded continuously and the others can be monitored and manually recorded through an indicator instrument. Two air flow meters will be used to measure the amount of air that passes into the chambers and through the wall specimen. One of the meters, of 3 cfm capacity, has been calibrated and found accurate to within 0.01 cfm.

The mechanical system, which is for the most part made up of the refrigeration, humidifying, and dehumidifying systems is in operation. A number of tests are scheduled for evaluating the performance of the mechanical system and the degree of control capability.

The refrigeration system is of the flooded coil type and has the cooling coil housed directly in the conditioned space to reduce penetrations of the chamber through which air might leak. Liquid refrigerant, R-12, is circulated through the coil and returned to the flash chamber where, after expansion and heating, the refrigerant is returned to the compressor in a continuous cycle. Four blowers are used to move air across the large-surface coil to provide better control of temperature. Circulation pattern of the air in the chamber is designed so that the air flow will not be directed against the wall specimen but parallel to it to give more uniformity of pressure against the wall surface.

It is anticipated that three of the six selected wall specimens can be tested during the coming six months. A more optimistic estimate at this time would be unrealistic since more tests must be made on the test apparatus to determine its capability. Action has been taken to retain the laboratory space at the present Washington site for an additional six months (until January 1, 1967) to finish the series of tests.

### 3.4 Weathering, Discoloration, Abrasion, etc.

The ability to predict the long-range performance of building materials is, needless to say, very desirable. It is important to assess, for instance, the durability of a paint when applied to the exterior of a building, even though the expected lifetime may be just a matter of a few years. It becomes even more important to evaluate the newer exterior siding materials with respect to durability when it is considered that these materials are now being sold with guarantees of up to 25 years. It is the purpose of this report to describe some experiments, to evaluate the data obtained, and to suggest conclusions concerning the weatherability of some commercial samples of exterior residential siding.

#### 3.4.1 Description of Samples

The materials used in this investigation were obtained from manufacturers and local distributors and arrived with the various abrasions and scratches received in transit. They were cut into several 2-3/4 by 5-7/8 inch panels which were used in subsequent tests. Thicknesses were determined with a micrometer; the paint was removed, for this purpose, with paint remover. Table 1 lists some of these figures and properties.

#### 3.4.2 Accelerated Weathering [1]

Two weatherometers were used to obtain data on the effects of aging. One was an Atlas twin carbon-arc machine which was operated on a 102-minute dry and 18-minute wet cycle. This instrument degrades samples via its rather strong ultraviolet emission and the effects of periodic water sprays. The second machine, an Atlas xenon arc weatherometer, more closely simulates the solar radiation. The water spray was not used with the xenon arc weatherometer.

#### 3.4.3 Color, Gloss and Washability

Gloss readings were taken with a Hunter Precision Glossmeter, with a specular reflectance of 60° [2]. Color readings were obtained with the Hunter Multipurpose Reflectometer [3]. The washability was determined using the Gardner Washability apparatus. This instrument consists of an electric motor mounted on a flat metal plate and a mechanism through which the motor imparts a reciprocating motion to a sponge, held in a metal box. A standard soiling medium is applied to the test panel which is then placed on the apparatus. A wet sponge, thoroughly rubbed with grit soap is placed in the holder and is rubbed across the test panel for a total of 35 cycles. Gloss and reflectance readings are taken after completion of the test [4]. Values of gloss, color, and washability were obtained before and after weathering in the twin arc weatherometer. They are given in Table 2.

#### 3.4.4 Abrasion Resistance

The abrasion resistance was determined using the NBS Jet Abrader [5]. The instrument basically provides a source of high speed abrasive particles which abrade the test specimen. The end point is reached when the substrate is bared. The time required to abrade through the specimen is a measure of its relative abrasion resistance. Parameters such as distance from test panel, speed of abrasive particles, angle of impingement, etc. are kept constant. Data for this test is given in Table 3.

#### 3.4.5 Flexibility

Flexibility is determined by bending samples of the surface film applied to flexible panels over 1/4 inch and 1/8 inch cylindrical mandrels. The smallest diameter mandrel over which a sample may be bent without causing cracks in the film is a measure of the film's flexibility [6]. See Table 4.

#### 3.4.6 Repaintability

Panels that were weathered 500 hours in the twin carbon arc weatherometer were coated, by brush, with a gray paint formulated according to Federal Specification TT-P-102a. The painted panels were placed back in the weatherometer and removed after 100 hours exposure. Adhesion was then determined by the knife test [7]. In this test a knife blade is used to cut through the film to the substrate. Adhesion is measured qualitatively by the rupturing of the surrounding area. The sidings that were factory painted gave results indicating fair to good adhesion, i.e., the paint lifted up in the form of a coil, with no shattering of the surrounding surface. The plastic panels and polyester coated panel did less well with slight shattering of the paint film. The Tedlar-coated panels were poorest in this respect as extensive shattering of the film occurred.

#### 3.4.7 Chemical Analysis of Weathering

A chemical method for analyzing the extent of degradation was employed. This method, developed at NBS for degradation of plastics, is a color reaction with a diamine, N,N-dimethyl-p-phenylenediamine (DMPDA) in a methanol-benzene solution: The amount of diamine reacting with a sample is measured using absorption spectrophotometry [8]. Results obtained are shown in Figure 1.

#### 3.4.8 Heat Aging of Plastic Siding

It was found that samples I and J are heat sensitive and tend to deform. At temperatures of 60°C both plastic samples soften while at 100°C the panels cannot support their own weight.

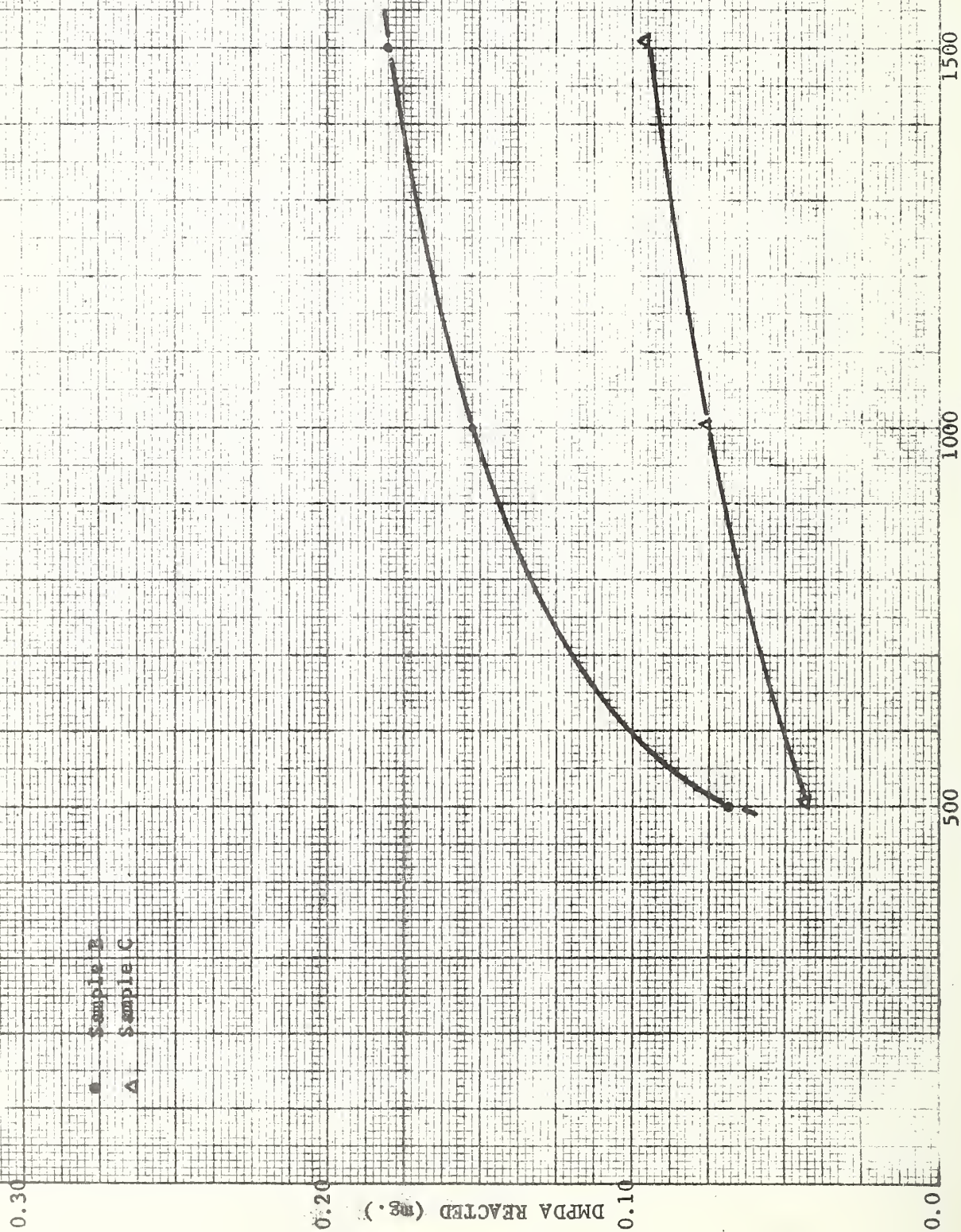


FIGURE NO. 1 EXPOSURE IN XENON WEATHEROMETER (HR)

#### 3.4.9 Discussion

The difficulty of correlating any accelerated weathering data with outdoor exposure is well known, as is the difficulty in comparing results obtained with one weatherometer with that of another [9]. In fact, exposures in different locations and at different times of year can also have a pronounced effect on the durability of coatings [10]. However, certain general conclusions can be drawn from inspection of Table 2. Gloss readings, although low to start with, decreased in value with time in the weatherometer. The values of L, the index of lightness, generally decreases for the light colored samples and stays generally the same for the darker colored ones. The darkening of the light colored samples is at least partially attributable to water staining. Longer aging periods would be necessary to detect significant differences between samples.

The flexibility does vary among the coatings and the Tedlar coated panel survives this test best. No differences were noted in this property after 500 hours of aging. However, it is doubtful whether this is of much significance as a measure of potential outdoor durability. Likewise, the abrasion resistance of Tedlar is also best. But here again, it would be premature to conclude that the painted panels would fail in use due to their relatively poor abrasion resistance. Repaintability is, of course, a significant property and may greatly influence the choice of an exterior siding. But in this case, the manufacturers may have recommendations regarding repainting. The susceptibility of the plastic siding to softening on heating may be significant in the long run because this is a structural member and must at least support its own weight.

Finally, it should be noted that a chemical colorimetric method shows great promise as a predictor of degradation, as results show up earlier in this method than in the standard gloss and color changes.

#### 3.5 Impact Resistance

In considering the impact resistance to be expected from house siding or cladding, the question is what kind of impact is likely to be encountered in service. One of the causes of impact damage is from baseballs, stones, and other missiles resulting from children at play. In a previous report, it was shown that a hard thrown baseball is comparable with respect to damage to

house siding to a steel ball, 1-3/4-inch in diameter, weighing 0.79 lb, dropped from a height of 10 feet. Another source of damage is accidental striking with garden tools, etc. A third source is hail damage, the incidence and severity of which depends on the locality. From a study of meteorological data, it appears that a 10-foot drop with a 1-3/4-inch diameter steel ball represents only about one-fourth the kinetic energy of a hailstone of the same diameter. However, the impact from this drop is sufficient to damage most house siding. Hailstones are not generally very hard frozen, even pure ice is much softer than steel, and part of the energy of impact of hailstones is undoubtedly dissipated in melting, plastic flow, and shattering. Hence steel balls do not simulate hailstones very well. Investigators in South Africa have simulated hail damage by firing ice balls from an air gun.

### 3.5.1 Tests on Whole Sections of House Siding

Various kinds of house siding or cladding were mounted in the manner actually used in houses on a frame, 18- by 27-inches, of 1/2-inch plywood, backed by 2- by 4-inch studs, 16 inches on centers. The frame was long enough for two or three 17-inch lengths of siding, depending on the width of the material, and was provided with retractable legs, so that the frame could be placed at a 45° angle as well as flat on the floor.

Some of the tests were performed at a 90° angle with the frame resting flat on the floor, a steel ball being dropped vertically through a guide tube. The frame was positioned so that the desired area would be struck by the ball, either a flat surface or the edge (butt or return). The steel ball was 1-3/4 inch in diameter and weighed 0.79 pound. The results of these tests are summarized in Table 5. Only qualitative visual observations were made, with no measurements. Cement asbestos shingle was tested above and below the line of overlap of shingles instead of on the flat surface or the edge. This material is apt to crack from impact above the line of overlap, at a point where the shingle is unsupported. In supported areas, as just below the overlap, it is resistant to impact. Vinyl siding is apt to crack and split from impact at the edge or return but is highly resistant to impact on a flat surface. Aluminum and wooden siding dent easily on impact and the edge or butt is apt to become deformed. Plywood coated with Tedlar is comparable to Douglas fir wooden siding. Hardboard coated with polyester is very resistant to impact, the only effect noted being a chipping of paint at the end of the butt due to impact on the upper side.

The other tests were performed at a 45° angle with an impact dart as described in the American Standard Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways, ASA Z26.1-1950. In tests reported in Table 6, a blunt tip was used for the dart, cylindrical in shape, the dart and tip weighing 0.52 pound. In tests reported in Table 7, a pyramidal tip was used at the end of which was a steel ball, 1/8 inch in diameter. The weight of the dart and tip was 0.44 pound. The dart was also dropped through the guide tube onto the desired area of the mount. The blunt tipped dart had an effect on cement asbestos similar to that of the steel ball. However, the dart tended to scuff the material rather than produce slight dents, as with the steel ball. The behavior with vinyl siding was also similar except for more scuffing. With aluminum siding there was also more scuffing and less deformation at the edge or butt. Wooden siding and plywood coated with Tedlar tended to splinter and crack on impact with the blunt tipped dart, as well as to dent. With the dart, there was no tendency for hardboard coated with polyester to chip paint at the end of the butt but this material scuffed. Impact with the ball point dart failed to crack cement asbestos shingle but produced scuffing. Behavior with other materials was similar to that of the blunt tipped dart.

### 3.5.2 Tests on 6- by 8-inch Pieces of Siding Material

In these tests, 6- by 8-inch pieces of siding or cladding material were mounted on plywood. In one type of mount, the siding material rested flat on a 1/2-inch thick piece of plywood. In the other type of mount, the siding material rested on two pieces of plywood, 1/2-inch thick by 1- by 6-inches, fastened to a 1/2-inch thick plywood backing, such that there was an unsupported span, 6 inches long by 6 inches wide. Either mount could be placed flat on the floor for a 90° impact or at a 45° angle on a wooden frame. The 1-3/4 inch diameter steel ball was dropped as close as possible to the center of each specimen.

Tests on specimens supported entirely by plywood are summarized in Table 8. The depth of the dents was measured with a dial gauge, although accurate readings could not be obtained with cement asbestos shingle, owing to the roughness and unevenness of the surface. In order to measure the depth of the dents in aluminum siding, an area, about two inches square, was cut around each dent and placed on a metal plate over a hole in the plate slightly larger than the dent. This was then subjected to pressure in a hydraulic press. The aluminum sheet was then flat enough to provide a reference while backed by the metal plate. Cement asbestos shingle was not cracked by this type

of impact but was dented and scuffed. Aluminum, redwood, and Southern yellow pine were dented about equally, while Douglas fir siding, plywood coated with Tedlar and cement asbestos containing wood fibers were somewhat more resistant to denting. Hardboard coated with polyester was undamaged except for slight scuffing from impact at a 45° angle. Vinyl siding was not affected at all by this type of impact test.

Tests on specimens supported at two ends, leaving 6- by 6-inch unsupported span, are reported in Table 9. The impact from the steel ball dropped only one foot at a 90° angle was sufficient to crack cement asbestos shingle. A drop of 2 to 6 feet at a 45° angle was required to crack the shingle. Cement asbestos siding containing wood fibers was cracked by a 3-foot drop at 90° and by a 6-foot drop at 45°. Aluminum siding was bent and dented, while vinyl siding was not affected by a 10-foot drop.

#### 3.5.3 Tests on 3- by 4-inch Pieces of Siding Material

This test was performed only on pieces of siding material supported at two ends, leaving a 3- by 3-inch unsupported span. Most siding materials were more vulnerable to this test than to the preceding test on 6- by 8-inch pieces of material. Cement asbestos shingle was cracked from a drop of only 6 inches and cement asbestos containing wood fibers was cracked from a 1-foot drop. Aluminum was bent and dented slightly from a 6-inch drop. Again, vinyl siding was not affected by a 10-foot drop.

#### 3.5.4 Effect of Temperature

Vinyl siding was found to be more brittle at 0° F than at 70° F when tested according to ASTM D-746.

#### 3.5.5 Discussion of Results

In evaluating house siding or cladding, it must be borne in mind that the siding material is part of a system and the mode of application must be considered. For example, it is important to note whether there are unsupported areas which might be especially vulnerable to impact. This is why tests were performed on unsupported as well as supported areas. The tests with 6- by 8- and 3- by 4-inch specimens were designed to isolate different features of the systems and compare the characteristics of these features. The Izod and Charpy tests are not suitable for all types of siding materials and the test with steel ball and unsupported span provides sufficient information as to relative impact strength. The

test with steel ball and supported material provides information on hardness which is adequate for the purpose and cheaper and more convenient than the conventional Rockwell test. Moreover, the steel ball test has been related to objects which customarily damage house siding.

The same observations and measurements cannot be applied to all siding materials because of their physical properties, such as the nature of the surface or the reaction of the material to impact. Soft materials, such as wood and sheet aluminum are dented on impact and impact resistance can be stated in terms of height of drop and depth of dent. However, unsupported aluminum siding is bent out of shape to such an extent that this masks the extent of denting. Brittle materials, such as cement asbestos shingle, are more apt to crack and impact resistance can usually be stated in terms of height of drop required to crack the material. Impact produces other effects on cement asbestos, as some denting and scuffing, but since the surface is rough and uneven, the depth of the dents cannot be measured accurately.

Aside from the shape of dents produced by different shaped missiles, the main difference between the results from impact with the steel ball and the impact dart was that the dart cracked and splintered wooden siding. Since hailstones are roughly spherical in shape, the dart is even poorer than the steel ball in simulating hail damage. The dart would roughly simulate damage by garden tools, etc.

#### 3.5.6 Recommendations

It seems likely that a continuation of this type of work will result in a rating system based on the kind of impact tests described. The following is a preliminary rating system:

Drop a steel ball, 1-3/4 inch in diameter, weighing 0.79 lb., from a height of 3 feet at a 90° angle on a piece of siding 3- by 4-inches, supported at two ends, so that there is an unsupported span 3- by 3-inches. If the material cracks or shatters, it is brittle and is in the class of cement asbestos shingle. If it bends out of shape, it is flexible and soft, like aluminum siding. Some siding might crack at low temperature (0° F) and establish another class of material.

Drop the steel ball at a 90° angle from a height of 6 feet on a piece of siding material supported by plywood. If there is a dent more than 10 mils deep, the material is soft, in the class of wooden siding.

If the material survives these tests with no damage, it should be considered to be in a superior class, as coated Masonite, with respect to impact resistance.

It is unnecessary to test at a  $45^\circ$  angle as this merely reduces the force on the siding due to less force vector acting on the surface and sliding of the missile due to low friction.

### 3.6 Heat Transfer

The heat transfer through exterior walls can be divided into two different categories, the sum of which will give the total heat transferred at a specific time. The first category covers the steady-state effect, and includes the heat transferred by means of a constant temperature difference between the mean temperature of a weather cycle exterior to the wall and a constant temperature adjacent to the interior surface of the wall. The steady-state effect is the best understood method of heat transfer and is presently used for estimating the heat transfer characteristics of exterior walls because only the thermal resistive effect of a wall need be computed (i.e., only the thermal conductivities of the components of exterior walls and inside and outside heat transfer coefficients need be known).

The second category includes heat transferred by means of time-varying temperature fluctuations occurring in a weather cycle, and according to the nature of the weather cycle, this category can be termed either the transient or steady periodic effect. The transient or steady periodic effect has not been given widespread practical application in the past. Several reasons may be advanced for this; namely, the mathematical solutions which include these effects are fairly complicated, a representative weather cycle cannot be well-defined for a given locality, season, etc., and the thermal diffusivities of the components of an exterior wall must be known. The introduction of thermal diffusivity which is inversely proportional to heat capacity gives a thermal capacitance to the exterior wall which, when coupled with the thermal resistive effect, determines the time-lag of the heat transfer rate at the interior surface of a wall. The modulation of heat transfer rate at the interior surface by the inherent thermal capacitances of the components of a wall is governed by thermal response parameters.

For the purpose of the present investigation, the thermal response parameters were termed "effective thermal conductance" and "effective thermal diffusivity". The thermal response parameters of a specific (nonhomogeneous) wall were set equal to those of a homogeneous (one-material) wall of the same thickness which exhibited the same thermal response at its inner surface to an imposed temperature variation at its exterior surface.

A mathematical analysis was performed for the single homogeneous wall and the composite non-homogeneous wall consisting of from two to four component materials. For a proposed experimental setup, it was decided to apply a simple sine-wave temperature variation of a given period on the exterior surface of a wall. On the interior surface, a buffer material of known thermal properties was proposed, with a constant temperature maintained at its exposed surface. With these boundary conditions, the temperature as a function of time measured at the interface of the wall and buffer enables calculation of the effective thermal response parameters.

The results of the mathematical analysis on some representative walls showed:

1. The thermal response parameters varied for a given wall with the period of a cycle. For very large periods the "effective conductance" approached the steady-state conductance for the wall. If it were possible to assign a representative period to weather cycles, the thermal response parameters would have some meaning.

2. Positioning of the various components of a wall has considerable effect on the values of the thermal response parameters. For example, placing a low thermal conductivity, low thermal heat capacity material (insulating material) exterior to a high thermal conductivity material (masonry) gives considerably different thermal response parameters than for the case where the materials are reversed in position.

3. The placing of a buffer which in itself has some heat capacity effects has a deleterious effect on the determination of the thermal response parameters. Further investigation for a proposed experimental setup will include replacing the present assumed buffers by a buffer with a negligible heat capacity, i.e., an air space and an interior panel maintained at a constant temperature.

It is concluded that because the periodicity of the exterior surface temperature materially affects the thermal response parameters, attention must be given to selecting a period and waveform for test measurements that will be reasonably representative for walls in service, at least well enough for comparing different walls. In brief, the task is to decide whether a simple sine-wave of a suitable period can be taken as an acceptable approximation to probable variations of building exterior surface temperatures under use conditions, taking into account both air temperature changes and solar heat absorption. If this can be answered affirmatively, it will be feasible to develop a test method for determining the dynamic thermal performance of walls under representative conditions.

#### 4. REFERENCES

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## 5. TABLES

Table 1. Characteristics of Exterior Siding

Sample Designation	Description	Color	Total Thickness (mils)	Thickness of Coating (mils)
A	Tedlar film on aluminum	White	25	2
B	Painted aluminum	White	23	1
C	Painted aluminum	White	24	1
D	Textured painted aluminum	Beige	30-35 <sup>(1)</sup>	1 <sup>(1)</sup>
E	Painted aluminum	Dark brown	24	1
F	Painted aluminum	Dark Gray	25	1
G	Tedlar film on plywood	White	355	2
H	Painted galvanized steel	White	21	1
I	Solid plastic	White	45	--
J	Solid plastic	Light green	50	--
K	Polyester film on masonite	White	395	2
L	Painted cement asbestos	Light green	150-200 <sup>(1)</sup>	1 <sup>(1)</sup>

(1) Because of textured finish, the figures are rough estimates.

Table 2. 60° Gloss and L Values After Aging in Twin Arc Weatherometer and After Washability Test

	0 Hrs.				500 Hrs.				750 Hrs.				1500 Hrs.			
	Before Wash		After Wash		Before Wash		After Wash		Before Wash		After Wash		Before Wash		After Wash	
	60° Gloss	L	60° Gloss	L	60° Gloss	L	60° Gloss	L	60° Gloss	L	60° Gloss	L	60° Gloss	L	60° Gloss	L
A	11.4	86.0	14.3	85.0	14.5	82.6	17.2	84.6					10.8	80.0	13.6	82.5
B	3.6	87.5	3.2	83.4	2.8	85.5	4.2	85.0					2.4	84.6	3.2	76.5
C	6.0	90.0	7.8	89.8	5.5	86.5	8.8	87.5					5.0	82.6	7.2	85.2
D	4.5	65.5	3.6	62.0	3.0	64.0	3.7	64.0					2.6	60.8	3.4	63.5
E	12.3	22.0	14.4	21.6	10.4	22.6	12.9	22.3					8.2	23.6	10.4	22.8
F	7.9	35.4	11.0	34.6	6.5	35.6	8.2	35.0					5.8	36.0	7.4	34.0
G	18.5	85.5	17.0	86.0	16.0	83.6	16.0	85.0	16.2	83.0	14.8	84.5				
H	10.2	85.5	11.4	86.5	8.8	84.2	9.6	84.4	8.4	83.8	7.8	83.6				
I	8.5	93.5	7.6	90.0	7.6	89.6	7.2	88.0	7.0	89.0	6.4	88.0				
J	8.5	75.0	7.4	74.8	8.0	72.5	7.4	73.5	6.2	71.4	6.6	71.5				
K	9.0	86.5	7.0	85.4	8.4	85.0	8.0	85.5	8.4	84.5	8.2	84.2				
L	2.0	63.5	2.0	62.0	2.0	63.0	2.0	61.0	2.0	62.0	2.0	61.4				

Table 3. Abrasion Resistance

Sample Designation	Time Required to Abrade (Sec.)
A	58
B	3
C	3
D	2
E	2
F	2
G	51
H	1
I	(a)
J	(a)
K	8
L	2

(a) Test not applicable to these samples.

Table 4. Flexibility

Sample	Smallest Diam. Mandrel (inch)		Smallest Diameter Mandrel (500 Hrs.) (In)	
A	1/8		1/8	
B	1/8	Incipient Cracking	1/8	Incipient Cracking
C	1/8	Incipient Cracking	1/8	Incipient Cracking
D	1/4		1/4	
E	1/4		1/4	
F	1/8	Incipient Cracking	1/8	Incipient Cracking
G	(a)		(a)	
H	1/4		1/4	
I	(a)		(a)	
J	(a)		(a)	
K	(a)		(a)	
L	(a)		(a)	

(a) Test not applicable.

Table 5. Drop-Impact Tests at 90° Angle on Sections of House Siding Mounted on an 18- by 27-inch Wooden Frame, using a 1-3/4-inch Diameter Steel Ball. Weight of Ball 0.79 Pound.

<u>Siding Material</u>	<u>Tests on Flat Surface</u>		<u>Tests on Butt or Edge</u>	
	<u>Height of drop, ft.</u>	<u>Visible Damage</u>	<u>Height of drop, ft.</u>	<u>Visible Damage</u>
Aluminum	3	Noticeable dent	3	Dent; some deformation
	6	Deeper dent	6	Deep dent; considerable deformation
	10	Same but greater effect.	10	Same but more
Cement Asbestos*				
Brand A	3,6	None		
	10	Dent; long crack above overlap.		
Brand B	3	Cracked on drop above overlap.		
	3,6,10	No damage on drops below overlap.		
Hardboard coated with Polyester				
	10	None	3,6,10	Chipping of paint at end of butt.
Plywood coated with Tedlar				
	3	Slight dent	3	Slight dent
	6	Somewhat deeper dent	6	Deeper dent
	10	Noticeable dent	10	Deep dent; deformation
Vinyl				
Brand A	10	None	6	None
			10	Cracked; piece knocked off
Brand B	10	None	5	No damage in 2 tests; slight denting in 2 tests.
			6	Dent in 1 test; crack, split in another test.
			10	Crack, split
Wood				
Douglas fir	3,6	Slight dent	3,6	Slight dent
	10	Deep dent	10	Dent, deformation
Redwood	3	Dent	3	Dent, deformation
Southern				
Yellow Pine	3,6	Slight dent	3,6	Slight dent
	10	Deep dent	10	Dent, deformation

\* Cement asbestos shingle was tested on areas above and below where shingles overlap instead of on the flat surface and on the butt.

Table 6. Drop-Impact Tests at 45° Angle on Sections of House Siding Mounted on an 18- by 27-inch Wooden Frame, using a Blunt Tipped Dart. Weight of Dart 0.52 pound.

<u>Siding Material</u>	<u>Tests on Flat Surface</u>		<u>Tests on Butt or Edge</u>	
	<u>Height of drop, ft.</u>	<u>Visible Damage</u>	<u>Height of drop, ft.</u>	<u>Visible Damage</u>
Aluminum	3	Scuffing; slight dent	3	Small dent; coating removed
	6	Deep dent; scuffing	6	Fair sized dent; scuffing
Cement Asbestos*				
Brand A	3,6	Slight scuffing		
	10	Scuffing; removal of coating; long crack above overlap.		
Brand B	3	No damage above or below overlap.		
	6	Scuffing		
	10	Scuffing; cracking above overlap.		
Hardboard coated with Polyester				
	3,6	Scuffing	3,6	Dart slipped and scuffed lower panel.
Plywood coated with Tedlar				
	3	Scuffing	3	Scuffing; break in coating
	6	Dent, break in coating	6	Dent, break in coating, deformation.
	10	Deep dent, splintering of plywood, peeling of coating	10	Deep dent, splintering, peeling, deformation.
Vinyl				
Brand A	6	Scuffing	6	Scuffing
	10	Scuffing	10	Noticeable dent.
Brand B	6	Scuffing	6	Scuffing
	10	Considerable scuffing	10	Chipped off piece
Wood				
Douglas fir	3,6,	Progressively deeper dents	3,6,	Denting, cracking, splintering
	10		10	
Redwood	3	Noticeable dent	3	Noticeable dent
	6	Larger dent	6	Chipping, splintering
Southern Yellow Pine	3,6,	Progressively deeper dents	3,6,	Denting, cracking, splintering
	10		10	

\*Cement asbestos shingle was tested on areas above and below where shingles overlap instead of on the flat surface and on the butt.

Table 7. Drop-Impact Tests at 45° Angle on Sections of House Siding Mounted on an 18- by 27-inch Wooden Frame, using a Ball Point Dart. Weight of Dart 0.44 pound.

<u>Siding Material</u>	<u>Tests on Flat Surface</u>		<u>Tests on Butt or Edge</u>	
	<u>Height of drop, ft.</u>	<u>Visible Damage</u>	<u>Height of drop, ft.</u>	<u>Visible Damage</u>
Aluminum	3	Dent, scuffing	3	Small dent; removed coating
	6	Deep dent; scuffing	6	Scraped coating and slipped off.
Cement Asbestos*				
Brand A	3	Slight scuffing		
	6,10	Definite scuffing		
Brand B	3	No damage above or below overlap		
	6	Scuffing		
	10	Scuffing; no cracking above overlap		
Hardboard coated with Polyester				
	3	No damage	3	Slight scuffing
	6	Scuffing	6	Scuffing
Plywood coated with Tedlar				
	3	Dent; peeling of coating	3	Dent; peeling of coating; deformation.
	6	Deep, long dent	6	Chip, deformation
	10	Deep dent, splintering, long scuffed area	10	Small scuffed area with some chipping.
Vinyl				
Brand A	6	Scuffing	6	Dent
	10	Scuffing, long dent	10	Scuffing
Brand B	6	Scuffing	6	Scuffing
	10	Long dent	10	Small chip
Wood				
Douglas fir	3	Noticeable dent	3	Noticeable dent; split
Redwood	3	Noticeable dent	3	Noticeable dent
	6	More noticeable dent; some splintering.	6	More noticeable dent
Southern Yellow Pine	3	Noticeable dent	3	Noticeable dent; split

\* Cement asbestos shingle was tested on areas above and below where shingles overlap instead of on the flat surface and on the butt.

Table 8. Drop-Impact Tests on 6- by 8-inch Pieces of House Siding Supported on Plywood, using a 1-3/4-inch Diameter Steel Ball.

<u>Siding Material</u>	<u>Height of Drop, ft.</u>	<u>Angle of Drop</u>	<u>Visible Damage</u>	<u>Dimension of Dent</u>	
				Max. diam. in.	Max. depth mils
Aluminum	3	90°	Dent	5/8	25
	3	45°	Dent	5/8	20
Cement Asbestos					
Brand A	10	90°	Dent; no cracking		18
	6,10	45°			5
Brand B	3	90°	Slight scuffing		
	6	90°	Scuffing		
	10	90°	Dent; crack part way across		
	3	45°	None		
Brand C	6	45°	Slight scuffing		
	10	45°	Scuffing		
	6	90°	Dent		20
	10	90°	Noticeable dent		26
	6	45°	Slight dent		
	10	45°	Slight dent		10
Cement Asbestos Containing Wood Fibers					
	3	90°	Dent	9/16	10
	6	90°	Dent	9/16	22
	10	90°	Dent	13/16	44
	3	45°	Dent	7/16	
	6	45°	Dent	1/2	5
	10	45°	Dent	5/8	15
Hardboard coated with Polyester					
	3,6,10	90°	None		
	3,6,10	45°	Slight scuffing		
Plywood coated with Tedlar					
	3	90°	Dent	1/2	10
	6	90°	Dent	3/4	20
	3	45°	Dent	1/2	5
	6	45°	Dent	5/8	7
Vinyl - Brand A					
	10	90°	None		
	10	45°	None		
Wood - Douglas fir					
	3	90°	Dent	9/16	8
	6	90°	Dent	7/8	25
	3	45°	Dent	1/2	6
	6	45°	Dent	7/8	16
Redwood	3	90°	Dent	1	30
	6	90°	Dent	1	48
	3	45°	Dent	5/8	15
	6	45°	Dent	5/8	27
Southern Yellow Pine	3	90°	Dent	3/4	22
	6	90°	Dent	3/4	40
	3	45°	Dent	1/2	6
	6	45°	Dent	5/8	27

Table 9. Drop-Impact Tests on 6- by 8-inch Pieces of House Siding,  
Supported at Two Ends, 6- by 6-inch Unsupported Spans

<u>Siding Material</u>	<u>Height of Drop, ft.</u>	<u>Angle of Drop</u>	<u>Visible Damage</u>
Aluminum	3	90 <sup>o</sup>	Dent; max. diam. 5/8 in.; max. depth 0.025 in.
	3	45 <sup>o</sup>	Dent; max. diam. 5/8 in.; max. depth 0.020 in.
Cement Asbestos			
Brand A	1	90 <sup>o</sup>	Crack all the way across
	6	45 <sup>o</sup>	Crack all the way across
Brand B	1/2	90 <sup>o</sup>	None
	1,2	90 <sup>o</sup>	Crack all the way through and across
	3	90 <sup>o</sup>	Broke in half
	1	45 <sup>o</sup>	None
	2	45 <sup>o</sup>	Fine crack all the way through and across
	3	45 <sup>o</sup>	Crack all the way through and across
Brand C	1	90 <sup>o</sup>	None
	2	90 <sup>o</sup>	Cracked all the way across; almost broke in half
	1	45 <sup>o</sup>	None
	2	45 <sup>o</sup>	Fine crack all the way across
	3	45 <sup>o</sup>	Crack all the way across
	6	45 <sup>o</sup>	Broke in half
Cement Asbestos containing Wood Fibers			
	2	90 <sup>o</sup>	None
	3,6,10	90 <sup>o</sup>	Crack all the way through
	2	45 <sup>o</sup>	None
	3	45 <sup>o</sup>	Shallow dent; no crack
	6,10	45 <sup>o</sup>	Crack all the way through
Vinyl - Brand A	10	90 <sup>o</sup>	None
	10	45 <sup>o</sup>	None

Table 10. Drop-Impact Tests at 90° Angle on 3- by 4-1/2-inch Pieces of House Siding, Supported at Two Ends, 3- by 3-inch Unsupported Span.

<u>Siding Material</u>	<u>Height of Drop, ft.</u>	<u>Visible Damage</u>
Aluminum	3, 6, 10	Bent and dented
	1, 2	Bent; slightly dented
	1/2	Slightly bent; slightly dented
Cement Asbestos		
Brand A	3, 6, 10	Shattered
	2	Broken in center and one end
	1	Cracked all the way across and through
	1/2	Fine crack all the way across
Cement Asbestos containing Wood Fibers		
	6, 10	Shattered
	2, 3	Cracked all the way across and through
	1	Cracked all the way across; slight dent
	1/2	Slight dent
Vinyl - Brand B	6, 10	None

## 6. APPENDIX

### A LABORATORY TEST FOR MEASURING SMOKE FROM BURNING MATERIALS

By

D. Gross and J. J. Loftus

#### ABSTRACT

As a result of extended laboratory investigations equipment has been assembled for quantitative measurement of the smoke produced when material is burned or pyrolyzed in a closed volume. This report provides the first complete description of the equipment. It is presented at this time to permit others, who so desire, to duplicate facilities for their own use. A later report will be prepared describing the work leading to development of the test method and reporting results obtained with a variety of building finish materials.

# A LABORATORY TEST FOR MEASURING SMOKE FROM BURNING MATERIALS

by

D. Gross and J. J. Loftus

## 1. Introduction

In a previous report [ 1 ], preliminary results were presented of the smoke production characteristics of several materials within the Rohm and Haas XP 2 Smoke Density Test Chamber [ 2 ]. These results indicated that a small-scale laboratory test chamber appeared to be a useful and desirable means for evaluating the smoke generation characteristics of materials under simulated building fire conditions. This study has been extended to establish test criteria and procedures which would permit simple, reproducible and meaningful smoke measurements. An improved test chamber has been designed and built for this purpose. This report gives a detailed description of the chamber design and the test requirements on which it was based.

## 2. Requirements

The basic requirements for any laboratory test method are that it be simple in concept and easy to operate, and that it yield realistic, reproducible results based on sound principles. It should be relatively insensitive to minor variables, but be capable of operating over a sufficiently wide range of conditions. In terms of smoke measurement, the following conditions were considered appropriate:

- A. The specimen be exposed and generate smoke from one surface only. This simulates the usual case in accidental building fires, and permits evaluation of the effectiveness of surface coatings in reducing smoke.
- B. The method be suitable for smoldering (non-flaming) as well as active flaming conditions.
- C. Smoke and combustion products (including water vapor) result only from specimen burning and not from the heat source.
- D. The results be reported in units providing a measure of smoke quantity and comparative obscuring power.

### 3. Test Equipment

#### A. Chamber

The smoke chamber consists of a 16 ga. sheet metal box, 3 ft x 2 ft x 3 ft high. As shown in Fig. 1 and 2, openings were provided to accommodate a photometer (C & I) with a 3-ft vertical light path, power and signal lead wires, air and gas supply tubes, an exhaust blower and damper (B), an aluminum foil blowout panel (D), and a hinged door with a window (E). The chamber is tightly closed and normally not ventilated during test. It is supported on an angle iron frame (L), on which are mounted the electric (N, O & P), gas and air controls (S & Q). A multi-range meter and timer, or alternately, a recorder, are used for taking data.

The interior of the chamber and all parts used therein are either anodized black or painted with a flat black paint which should be resistant to corrosive decomposition products.

#### B. Furnace and Control System

To provide a fairly uniform irradiance on the surface of the 3 by 3 in. square specimen, an electrically-powered furnace with a 2-15/16 in. diameter opening is used. As shown in Fig. 3 A, a 525 watt type "End" Silux heating element (D) is mounted within a 2-15/16 in. i.d. by 3-3/8 in. o.d. by 1-5/8 in. long ceramic tube (C), bored out to 3-1/32 in. i.d., 5/8 in. deep, to accommodate the heating element. Behind the heating element are mounted a 1/16 in. thick asbestos paper gasket (F), three 1/16 in. stainless steel spacing washers (G), and two 1/32 in. stainless steel reflectors with 6 holes (H) and 3 holes (I), respectively. The heating element assembly is centered with respect to the front 3/8 in. asbestos board (B), and the 3/8 in. asbestos board centering disk (J), by means of a 6-32 stainless steel screw (E), and the adjustment of the nuts on the end of this screw provides the proper spacing of the furnace components. Pyrex glass wool (W) is used to fill in the spaces in the heating element assembly. Two spacing rings (K) of 3/8 in. asbestos board, a rear cover (L) of 3/8 in. asbestos board, and a 4-in. o.d. by .083 in. wall by 4-1/8 in. long stainless steel welded sanitary tube (A), 180 grit polished inside and outside, complete the furnace assembly. Three sheet metal screws (M), No. 6 by 1/2 in., are used around the periphery at each end. Appropriate holes are provided in the centering disk for asbestos-covered copper lead wires to the heating element and in the rear cover for a motor base plug and six 1/2 in. ventilation holes on a 2-1/2 in. dia. circle.

Although the materials and dimensions used are given in detail, they are not considered critical, provided the construction can withstand continuous operation and provided the geometry of the furnace opening is not materially altered.

The control system consists (Fig. 2) of a temperature controller (M), two autotransformers (P), and a sensing thermocouple placed within and close to the surface of the ceramic core of the furnace opening. The temperature set point of the controller is arranged so that a radiometer, placed at the same location as the specimen, will measure the prescribed irradiance level. The two autotransformers provide high and low voltage levels (rather than on and off), and can be adjusted to minimize power fluctuations to the heating element.

### C. Photometric System

The light path was arranged vertically to reduce errors in measurement due to smoke stratification effects. The light source was a 30-watt, 120 volt, S-11, Type BLC, film viewer lamp powered by a voltage regulating transformer. It was mounted in a box (C, Fig. 2) extending above the top of the smoke chamber, which contained, in order, the source, a 7-diopter collimating lens and an adjustable metal finger. (See Fig. 4). A glass window, gasketed for smoke-tightness, was mounted permanently in the ceiling of the chamber. The lamp was always operated at the same voltage (and hence same color temperature, approximately 2630°K), and adjustments of the light intensity were made with the metal finger.

Another box (I, Fig. 2) containing the photometer was located directly below the source and attached to the bottom of the smoke chamber. Below a similarly mounted glass window in the chamber floor were, in order, a 7-diopter lens forming an image of the source, a 3/16 in. dia. circular stop in the focal plane of the lens, and a 1P39 single-stage vacuum phototube having an S-4 spectral sensitivity response. This lens and stop combination did not permit the receiver to register rays departing from parallel by more than a few degrees, and reduced to a negligible amount the effect of the "beam broadening" caused by smoke particles scattering light from the original beam.

The phototube circuit load comprised the input resistance of the recorder and an adjustable load resistor arranged to provide a convenient signal level. When the full-scale output for the clear, smoke-free condition was adjusted to 1 volt (using the metal finger and load resistor adjustments), ten-fold reductions in light transmission could be accommodated without appreciable loss in accuracy, by decade range changes of the recorder down to 0.1 millivolts full scale. This permitted the recording of reliable optical densities of about 4, corresponding to transmission values of .01 percent of the incident light. At the lowest levels of light transmissions, a correction becomes necessary for the dark current of the vacuum phototube, since this represents zero light transmission.

#### D. Specimen Holder

The 3 x 3 in. specimen is placed in a holder, Fig. 5, designed for rapid positioning and for maintaining, by means of the furnace support (Fig. 3 B), the specimen surface 1 1/2 inches in front of, and parallel to, the furnace opening. The furnace support also serves as a positioning mount for a radiometer, Fig. 6, which establishes the prescribed irradiance level at the specimen surface just prior to its exposure.

The stainless steel specimen holder is fabricated by bending and brazing (or spot welding) to give a 2-9/16 in. square exposed area. The back, edges, and front non-exposed surfaces of the specimen are covered with a single sheet of thin aluminum foil to prevent smoke passage at any but the exposed specimen surface. Behind the specimen is placed a 3 x 3 x 1/2 in. thick sheet of asbestos millboard (confirming to Federal Specification HH-M-351). A phosphor bronze spring and a steel pin are used to maintain a snug assembly.

When the proper spacing (9-3/8 in.) is maintained between the spacing tops of the furnace mount (Fig. 3 B), the loaded specimen may be quickly and accurately positioned by placing it on the support bars and sliding the radiometer or another holder to the limit of its travel.

#### E. Radiometer

The desired irradiance level ( $2.5 \text{ w/cm}^2$ ) at the specimen surface is measured by means of a circular foil radiometer of the type described by Gardon [3]. It is of simple construction, has a sufficiently rapid time-constant and produces an emf, which is nearly proportional to the irradiance level. The use of a reflective heat shield, with aperture, on the front of the radiometer, and a finned convector supplied with compressed air on the rear, help to maintain the radiometer body at a more constant temperature and to minimize effects due to variable convective and radiative losses. The receiving surface was spray-coated with an infrared-absorbing black paint containing a silicone vehicle.\* The absorptivity of the paint to visible and infrared energy is approximately 0.93 to 0.95 for a film thickness of 1 mil.

Details of the radiometer construction are shown in Fig. 6. The air-cooled radiometer was calibrated by placing it at suitable distances from a radiant energy source and measuring its electrical output as a function of the irradiance level, Fig. 7. The latter was determined calorimetrically by measuring the rate of temperature rise of a totally absorbing copper disk of known weight, area and specific heat.

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\* Type 8 X 906 SICON Flat Black Paint, Midland Industrial Finishes Company, Inc., Waukegan, Illinois.

#### 4. Suggested Test Procedure

All specimens, prepared in the 3 x 3 in. size, should be predried for 24 hours at 140°F and then conditioned to equilibrium with an ambient of  $73 \pm 5^\circ\text{F}$  and  $50 \pm 5$  percent relative humidity. The specimen should be representative of the material or assembly as intended for use and should be prepared by the intended application procedures. Where the intended application of a finish material is not specified, or may be any of several, the finish material may be prepared for test as follows:

- (a) Surface finish materials, in either liquid or sheet form, including those intended to control and reduce the smoke produced by supporting base materials, should be tested in the assembly or assemblies proposed for use. In the absence of specific information, the finish material should be applied to the smooth surface of 1/4 in. thick tempered hardboard using recommended (or practical) application techniques and spreading rates.
- (b) Liquid films, such as sealers, adhesives, etc., and other materials intended for application to noncombustible base materials or being tested for their inherent smoke contribution shall be applied to the smooth surface of 1/4 in. thick asbestos cement board of 120 pcf density, using recommended spreading rates.
- (c) Materials intended for air-backed applications, such as suspended ceilings or hanging drapes, shall be mounted in a specimen holder providing a 1/8 in. air space behind the specimen. This may be accomplished by use of an asbestos board back fitted with 1/8 in. thick, 1/4 in. wide asbestos strips at the borders.

To perform a test, turn on the electrically-powered furnace and associated controls. Place the radiometer in a specimen holder and position it in front of the furnace. Turn on the compressed air supply to the radiometer convector and adjust the flow rate (or pressure) to correspond to the value used for calibration. Adjust the controller temperature setting to produce a millivolt output of the radiometer corresponding to an irradiance of  $2.5 \text{ w/cm}^2$ . Adjust the two autotransformers to suitable voltage levels (approximately 70 and 90 volts) to minimize cyclic variations in irradiance.

Turn on power to the photometer light source and the recording or indicating meter. Using the metal finger and load resistor adjustment, set the output reading to full-scale on the 1-volt range. Verify the zero reading on the most sensitive range, and others if required, by shorting the meter input.

Mount a preconditioned specimen in a cool specimen holder using a single sheet of aluminum foil along the back, edges, and front inside surfaces of the specimen, taking care not to puncture the foil. Back the specimen with a sheet of 1/2 inch asbestos millboard and assemble into the holder snugly, using the spring and pin.

For non-flaming (smoldering) tests, place the loaded specimen holder on the bar supports and slide it into position by displacing the radiometer. Start the timer (or recorder chart) simultaneously. Turn off the air supply to the radiometer and close the door. Record values of light transmission versus time, making full-scale range changes (in decade steps for maximum convenience) as appropriate. Observe and note any characteristic smoking or burning patterns, the color and nature of the smoke, etc. Continue until a minimum light transmission value is reached or 15 minutes, whichever is lesser. Record the "dark current" light transmission by switching off power to the photometer light source and setting the recorder at a suitable high sensitivity. Verify the zero reading by shorting the meter input. Open the door a small amount and turn on the exhaust fan to clear the chamber of smoke. Discard the specimen and clear the chamber completely of smoke. With the photometer light on, record the final light transmission value under clear air conditions in the chamber, making the appropriate meter range changes. Clean the glass windows (ethyl alcohol generally is satisfactory) in preparation for the succeeding test.

For tests employing pilot ignition, supply gas to the pilot burner (see Fig. 5) at a rate of 200 Btu/hr (0.2 SCFH of natural gas, or equivalent). Ignite the horizontally oriented gas jet using an electrically powered platinum "hot wire". Swing the lighted pilot burner up to impinge on the specimen surface when the loaded specimen holder displaces the radiometer in front of the furnace. If the pilot burner is blown out during a test, reignite it using the platinum hot wire. Proceed as before.

## 5. Test Results

The result of a smoke measurement test of a material is a curve of optical density (per foot) versus time. The report of such a test should also include the following:

- (a) Identification of the material, including data such as density, thickness, and type of base material (if used).
- (b) Test conditions, including irradiance level ( $2.5 \text{ w/cm}^2$ ), flaming (pilot) or smoldering (no pilot) exposure, etc.
- (c) Important visual observations of specimen, color and nature of smoke, and test chamber conditions both during and after test.

The reduction in the light transmission caused by smoke in the photometer light path is measured using a recorder or a meter and timer. The transmission data is converted to optical density per foot using the relation:

$$D = \frac{1}{L} \left( \log_{10} \frac{100}{T} \right)$$

where T is the percent transmission and L = 3 ft is the length of the optical path.

For each test, retain a record of (a) the "dark current" light transmission (with photometer light source off and recorder set at a suitably high sensitivity), and (b) the final transmission value (after removing specimen and clearing chamber of smoke).

## 6. References

- [1] D. Gross, J. J. Loftus, and R. Harris, "Wall Cladding Materials: Smoke Production Measurements Under Simulated Fire Conditions", First Progress Report, NBS Report No. 8398, July 14, 1964.
- [2] Anon., "A Method of Measuring Smoke Density", NFPA Quarterly, 57, pp 276-87, January 1964.
- [3] R. Gardon, "An Instrument for the Direct Measurement of Intense Thermal Radiation", Rev. Sci. Inst., 24, pp 366-70, May 1953.



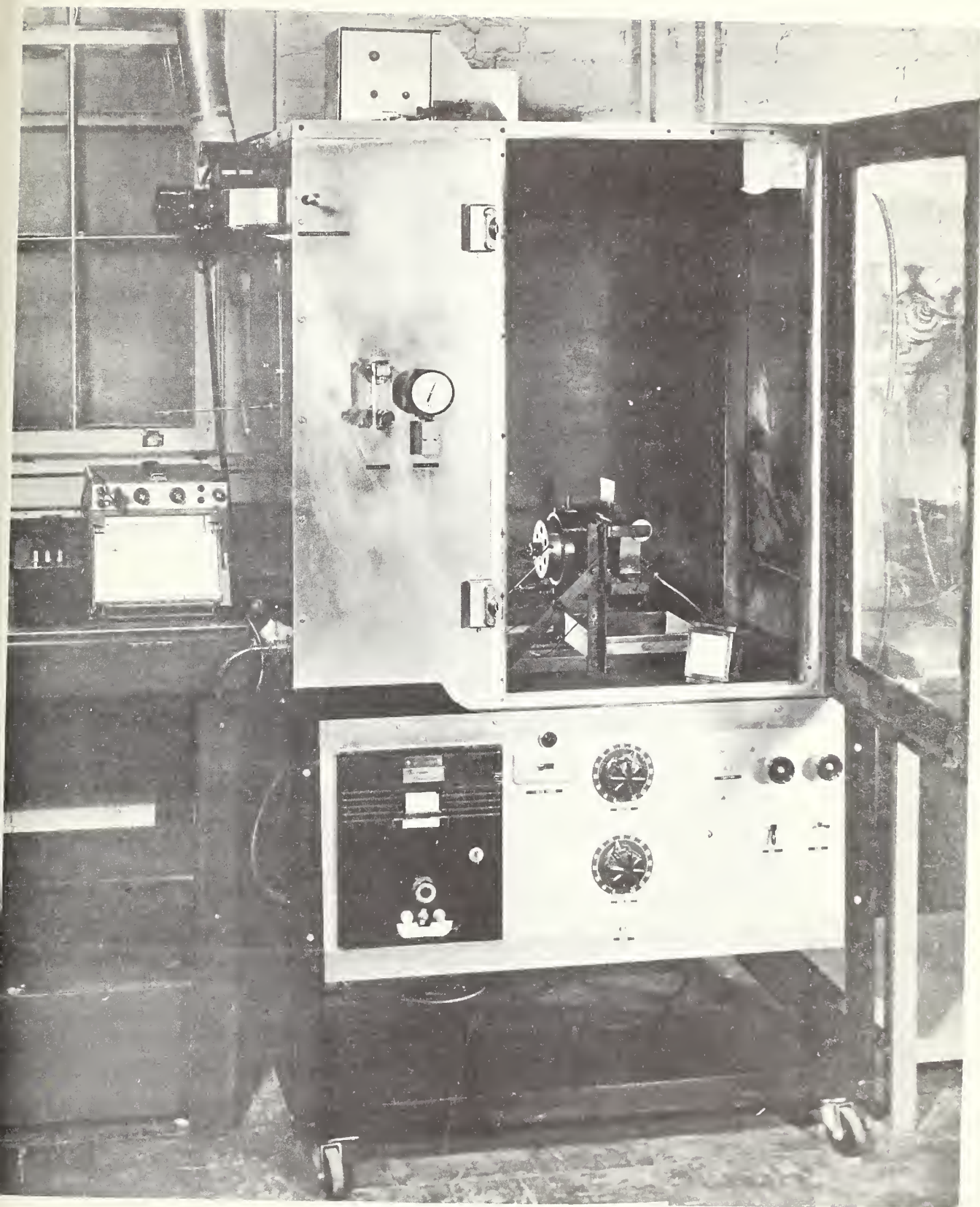


Fig. 1 - Smoke Test Chamber

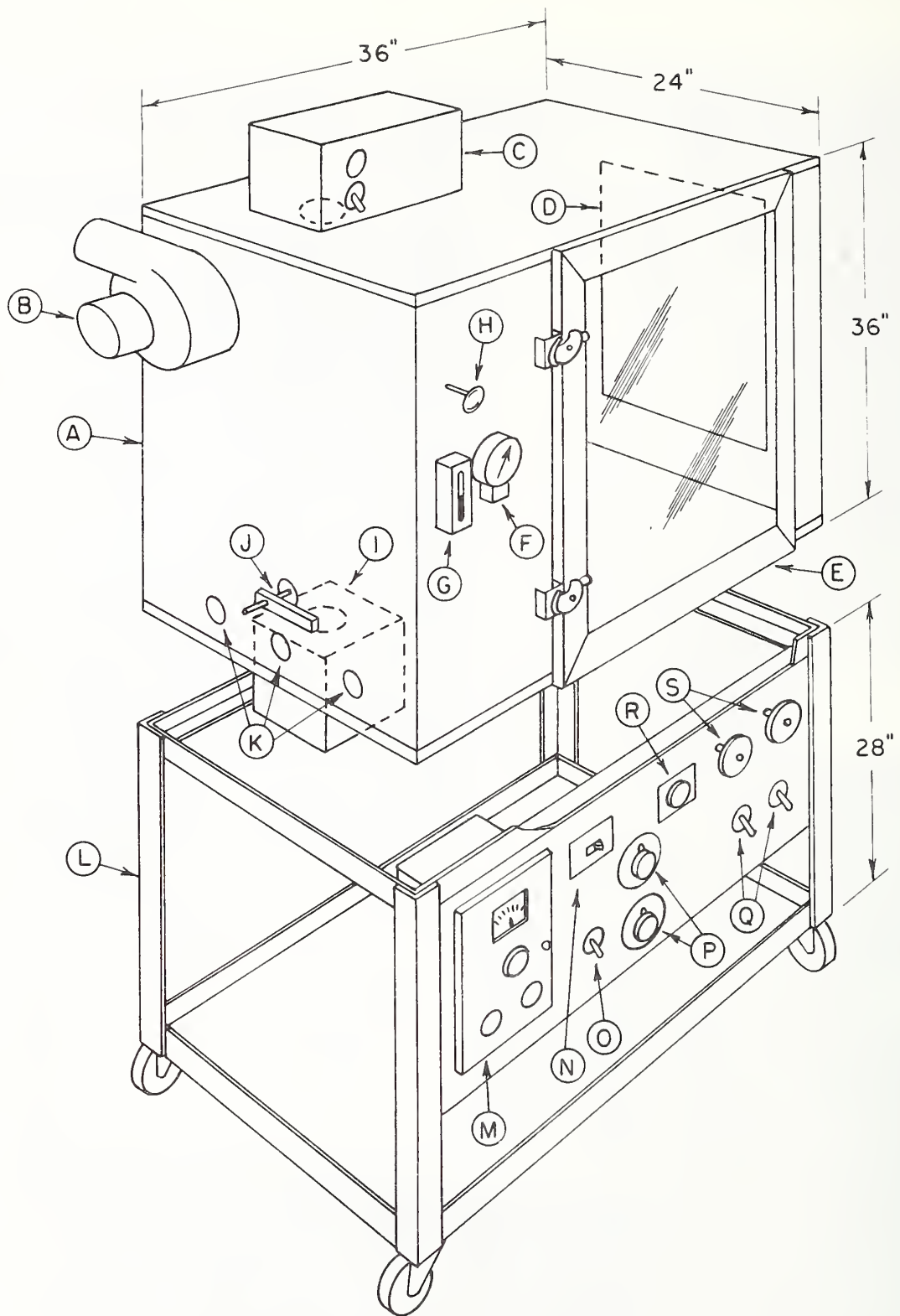


FIG. 2 - SMOKE CHAMBER ASSEMBLY

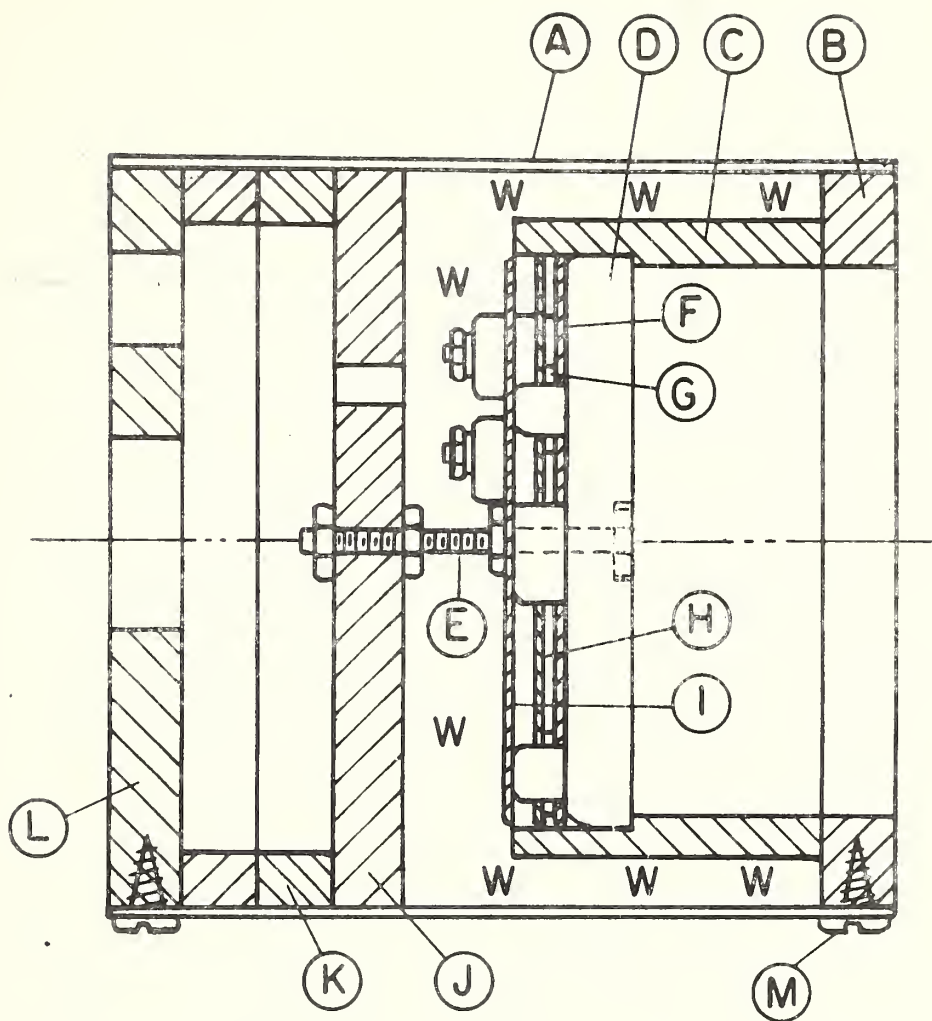


FIG. 3A-FURNACE SECTION



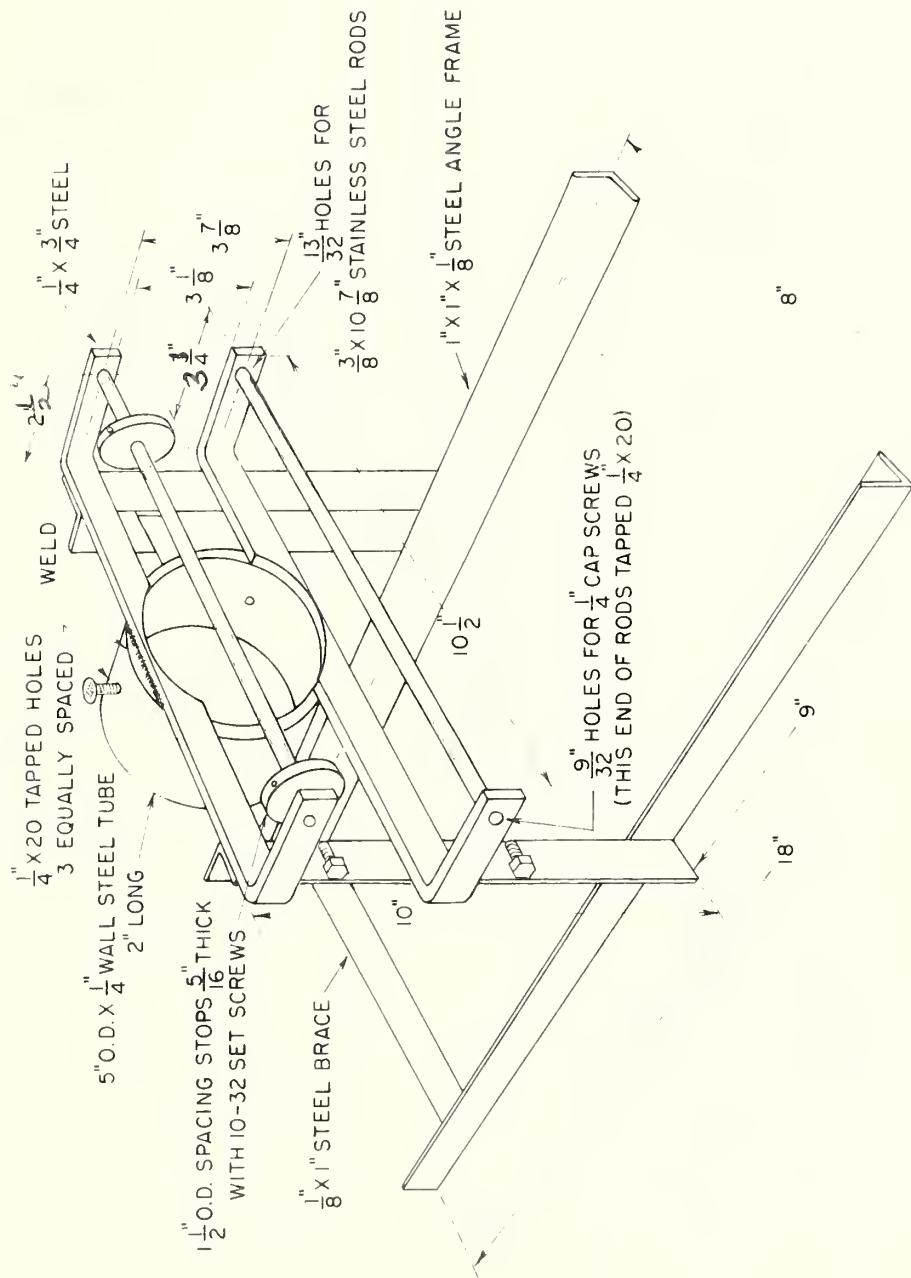


FIG. 3B - FURNACE SUPPORT



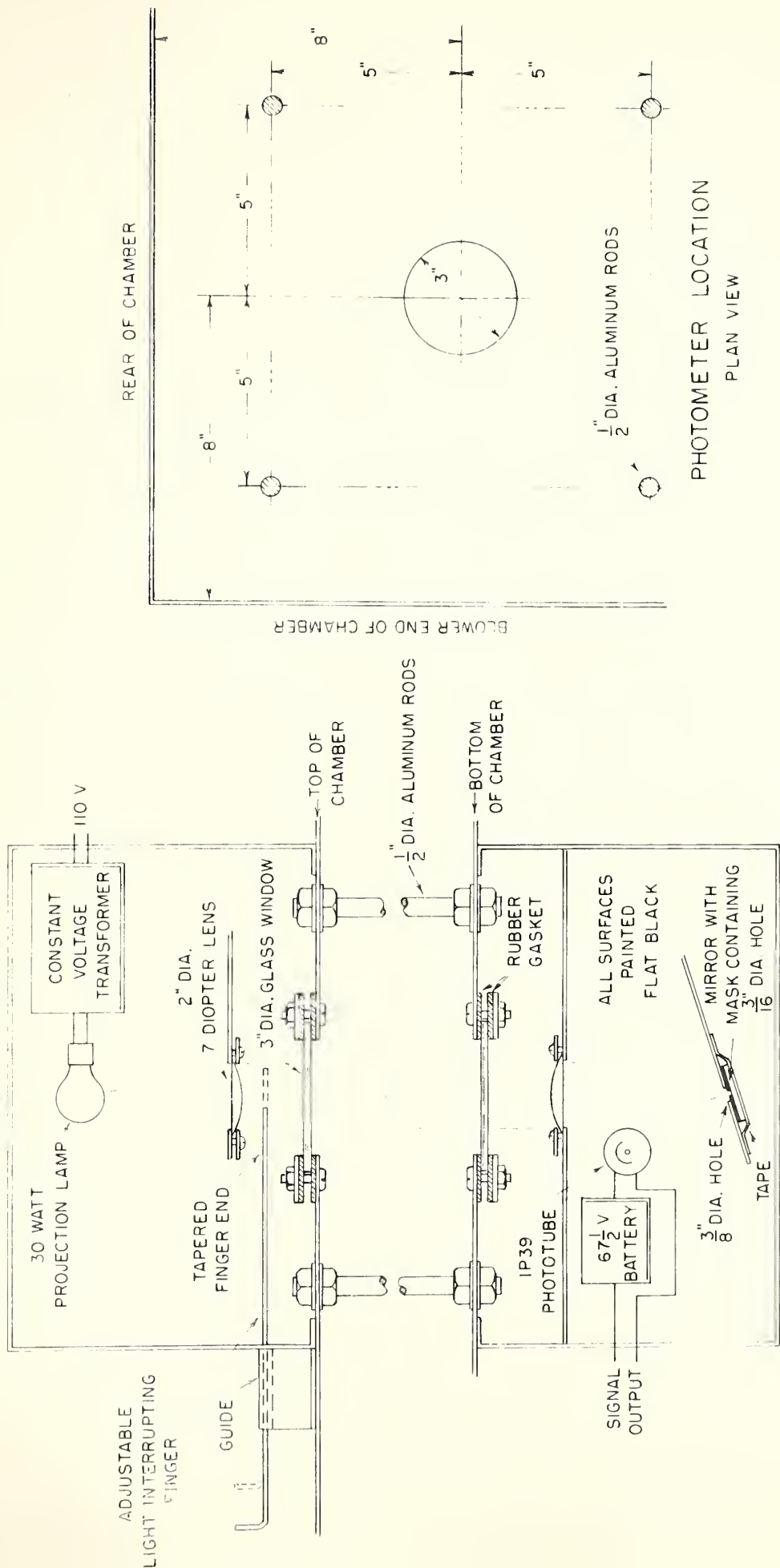
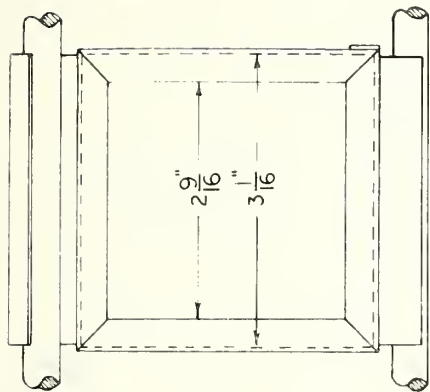
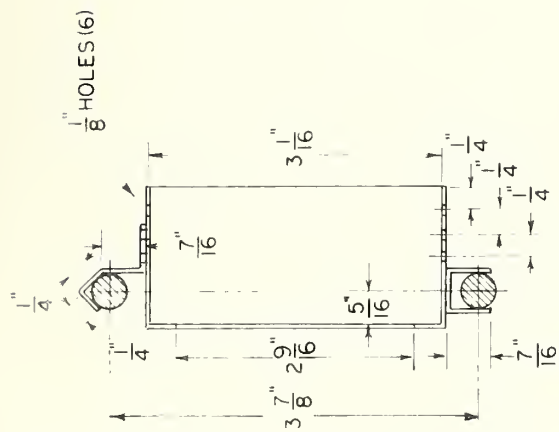
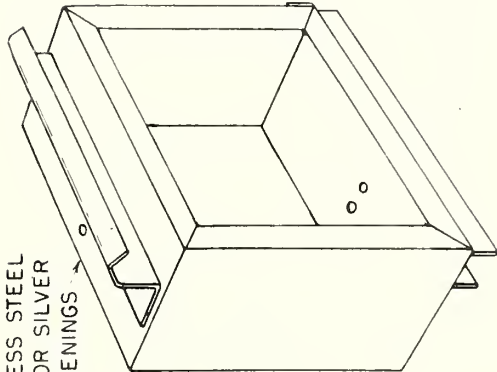


FIG. 4 - PHOTOMETER DETAILS





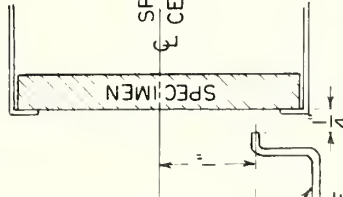
.025" STAINLESS STEEL  
SPOT WELDED OR SILVER  
BRAZED FASTENINGS



SPRING BENT FROM  
.032" X  $\frac{3}{16}$ " X 3"  
PHOSPHOR BRONZE

$\frac{1}{8}$ " DIA. STEEL  
RETAINING ROD

SPECIMEN RETAINER



SPECIMEN  
CENTERLINE

$\frac{1}{8}$ " O.D. X  $\frac{1}{32}$ " WALL  
STAINLESS STEEL TUBE

NATURAL GAS FLOW RATE  
0.2 CU. FT./MIN.

PILOT BURNER ARRANGEMENT

FIG. 5—DETAILS OF SPECIMEN HOLDER AND PILOT BURNER







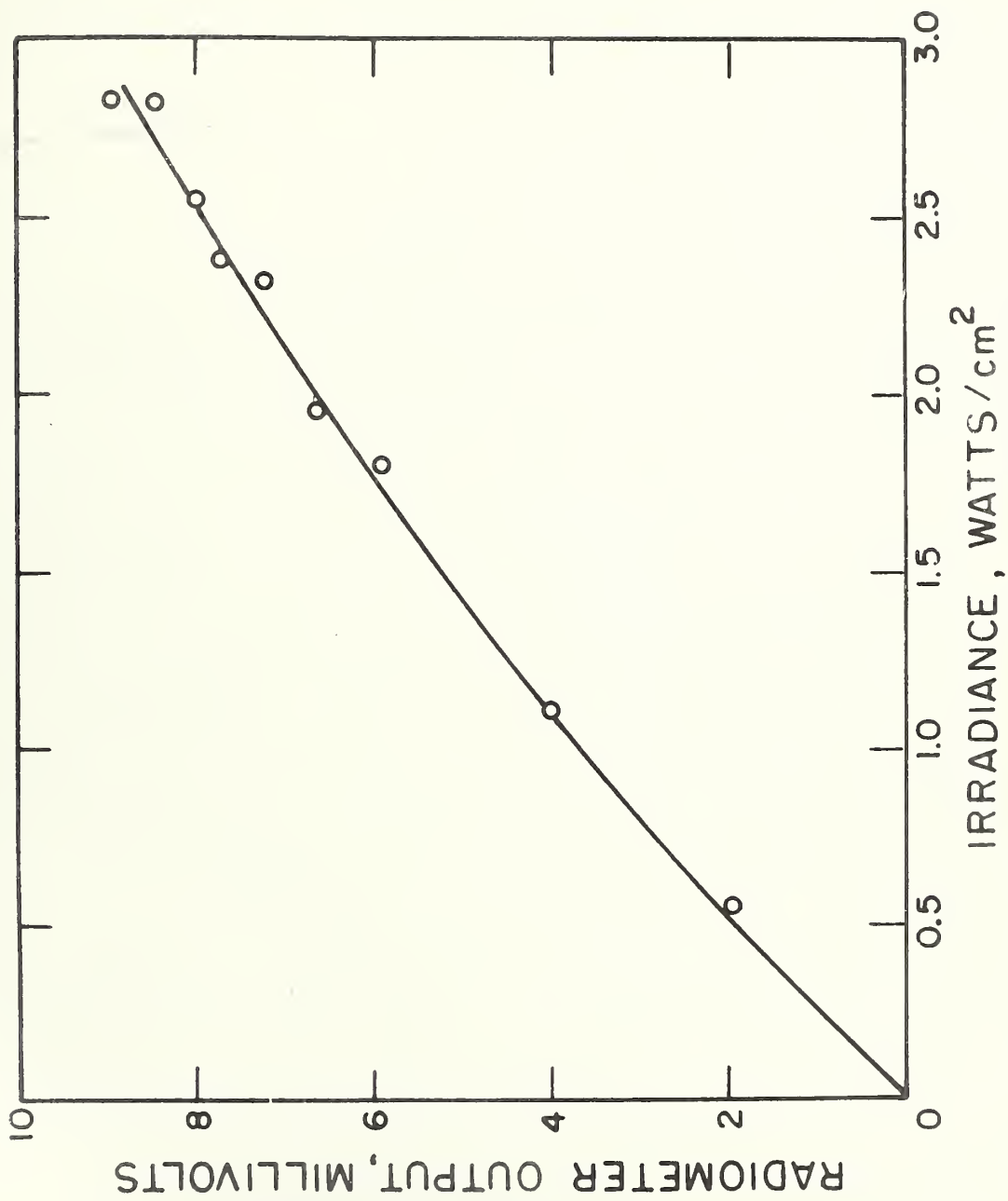


FIG.7 - RADIOMETER CALIBRATION CURVE





